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Abstract

THERMAL-DESIGN ASPECTS OF GAS-COOLED REACTORS

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Air, nitrogen, and helium are commonly used as coolants in U.S. gas-cooled reactors. Core power densities range from 2 KW/liter for the Experimental Gas-Cooled Reactor (EGCR) and 8-10 KW/liter for High Temperature Gas-Cooled Reactors (HTGR) to about 250 KW/liter in a preliminary design of a fast gas-cooled reactor. The ratio of pumping power to thermal power usually lies between 2% and 5%. Core outlet temperatures range from 1050F in the EGCR to 1400F in HTGR's. Fuel element surface and internal temperatures are in the range where heat transfer by radiation must be considered. Metallic-clad fuel elements have been used with uranium oxide dispersed in thin concentric cylindrical sheets or with uranium oxide in rod clusters. Graphite-clad fuel elements with uranium carbide fuel are used in HTGR's and pebble-bed reactors.

Heat-transfer experiments have been used extensively to determine local and average transfer coefficients for all these types of fuel elements. Mass-transfer experiments with naphthalene or benzoic acid have been used to determine heat-transfer distributions in complex situations. The heat-transfer correlations for parallel flow seem in general to be close to the standard correlations, although local deviations can be large and must be carefully investigated for metal-clad elements. For instance, the local heat-transfer coefficient in the Experimental Beryllium Oxide Reactor (EBOR) varies 20% to 30% around its average value.

Surface roughening has been investigated as a means of increasing surface heat transfer coefficients and improving core performance. Results have shown

that the number of fuel elements in a reactor can be reduced by as much as a factor of four by roughening only an optimized fraction of the surface. It has been shown for circular tubes that swirling of the gas coolant may give heat-transfer coefficients between 1.1 and 3 times those obtained with turbulent flows. The swirl may be introduced by tangential injection or twisted tapes.

Statistical determination of hot-spot factors is used for metallic-clad gas-cooled fuel elements. In ceramic fuel elements local hot spots are less important than the fraction of the fuel above a given temperature where fission-product release increases rapidly. The problem of cross flow between coolant channels in HTGR-type reactors has been shown not to affect appreciably the thermal analysis.

Special heat-transfer and pressure-drop correlations have been obtained experimentally for pebble-bed reactors. Thermal stresses in the spheres, levitation, and nonuniform flow distribution have been investigated.

As most of the thermal-design analysis is performed by numerical methods, numerous digital computer codes have been developed to analyze 2- and 3-dimensional problems. The finite difference equations resulting from the relevant differential equations are usually made implicit to avoid time-step limitations in transient problems. The resulting set of nonlinear equations is solved by iterative methods; nonlinear coeffieients (such as temperature-dependent properties and thermal radiation) are treated by re-evaluating the coefficients, as a function of the current temperature, between iterations.

In several gas-cooled reactors, the loss-of-coolant problem limits the power density and often determines the geometry of the fuel element. The thermal stresses generated by power or coolant transients may limit the freedom of design of ceramic fuel elements.